

SEAFLOOR EARTHQUAKE MEASUREMENT SYSTEM
Quarterly Report

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Contracting Agency:	Mineral Management Services Department of Interior
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Project Description

The objectives of the SEMS project are: (1) to design, develop, install, and interrogate sea-bottom seismic stations and, (2), to analyze the seafloor motion records to provide a seismic characterization of offshore oil and gas leasing regions. The principal areas of interest are offshore of Southern California, in the Southern Bering Sea, and near the Aleutian Islands. One SEMS unit was installed during 1985 in the Beta Field offshore of Long Beach, CA. A second unit is currently being developed for deployment off the coast of California, near Point Arguello. Given that sufficient government and industry funding can be obtained, the project will eventually emplace and monitor multiple SEMS units in areas of extreme seismicity.

Progress

During this quarter, various field, analytical, and laboratory tasks were undertaken. The two major activities during this quarter involved (1) the analysis of SEMS data and (2) the recovery and testing of the Beta Field SEMS unit.

FIELD WORK: SEMS INTERROGATIONS AND RECOVERY

Two routine Beta Field SEMS interrogations took place during October, 1987. The objective of these interrogations was to establish if SEMS had recorded any of the significant earthquakes which occurred in the proximity of SEMS during October, 1987. It was found that SEMS failed to detect any earthquake events. It is now clear that the SEMS earthquake-detection hardware and software is ineffective. The deficiencies associated with the triggering mechanism include: SEMS has significant electronic noise which obliterates subtle seismic motions; SEMS only uses the vertical component of acceleration for triggering (it has been found that sea-bed observations contain greatly reduced vertical motions relative to horizontal motions); and SEMS uses a relatively insensitive measure of earthquake strength for deciding which events are worth storing.

Based on the above facts, it was decided that the Beta-Field SEMS be recovered, redesigned and redeployed. In order to fully investigate the behavior of the SEMS unit, it was necessary to recover a fully operational and intact unit. Since the SEMS batteries were near the end of their useful life, the recovery operations had to be completed by the end of this quarter. A further constraint placed on the recovery operations was that the seismic probe, which was buried some five feet below the mud-line, be excavated. The following paragraphs describe the procedures used for this highly successful and cost-effective recovery operation.

The recovery operations were supported by Undersea Graphics, Torrance CA. Undersea Graphics (UG) operated a 40 ft boat (The Mother Goose) with a two man submersible (Snooper) on board. The purpose of this boat and submersible was to attach the required recovery cables to SEMS and to excavate the probe from the seafloor sediments. UG subcontracted for a larger, 80 ft. boat (Vicki Anne) to winch the SEMS on-board and return SEMS to port. The desired operations, as specified by Sandia, were contained in a Statement of Work to Undersea Graphics. In general, the proposed recovery operations were executed as planned.

The recovery operations began at 5:15 a.m. on December 8, 1987, when the Mother Goose left port from San Pedro, CA. We arrived at the SEMS site at 6:45 where the conditions were 10 mph winds with 6 ft. long ocean swells. From 6:50 to 7:20, the SEMS unit was interrogated. The interrogation indicated that SEMS was working as usual. The DAGS batteries were found to be 11.5 volts (down from 12.2 volts five weeks previous). There was one data record of interest (part of the November 24, 1987 Imperial Valley Earthquake) and this was uploaded and stored on magnetic tape. at about 7:20, the command was issued to release the DAGS buoy. By about 7:30, it was concluded that the buoy had failed to release.

In order to aid in the search to locate the SEMS unit, a system cycle was initiated between CARS and DAGS. The Mother Goose then traversed from east to west and buoys were placed at the points where communications between DAGS and CARS became intermittent. Similarly, the boat traversed from north to south and the extent of SEMS communications in this direction was noted. This limited the search area to a circle of about 100 yds in radius.

At about 8:00, the submersible Snooper was launched to find the DAGS unit. The initial launch location was near the center of the large circle previously indicated. Upon arriving at the bottom, Snooper began a circular search pattern with about 7-10 ft between concentric rings. The visibility was limited to about 10 ft. The location of the rings was marked on the bottom by a chain attached to Snooper and dragged along the bottom. Unfortunately, the chain soon became snagged, and the ring pattern had to be discontinued. At this point communications between the Mother Goose and Snooper tried to place Snooper in the expected location. The fathometer on Snooper was used to follow contours of 240 ft, and a buoy attached between Snooper and the surface was used to place Snooper in the center of the large communications circle. By about 9:30, it was obvious that this method was ineffective for finding SEMS. Sandia indicated that Snooper should return to the surface and attach a new drag chain. After attaching the chain and replacing the air tanks, Snooper dived for a second time at about 10:00. Circular ring patterns were begun. By about 11:15, the batteries on Snooper needed to be replaced.

Snooper had already created about a 70 ft. diameter ring pattern so it dropped a buoy near the center of the rings and returned to the surface for new batteries. At 12:00, Snooper dived for the third time and followed the buoy down to the ring patterns. The pattern was continued, and at approximately 1:00 p.m., SEMS was found.

Upon arriving at SEMS, about 10 minutes of video pictures were taken. For about the next 45 minutes, UG attempted to excavate the probe. Using the hydraulic manipulator, 100 lbs of force was applied to the probe cable. There was no apparent give in the probe at this force. At this point, an underwater pump was used to suck sediment around the cable. It was found that the suction operation was relatively ineffective since the hole quickly filled up. On UG's decision, the manipulator grabbed onto the cable and submarine ballast was released. This placed about 300 lbs of force on the probe cable. This did not remove the probe, and the sub returned to the surface at about 2:00.

By 2:00, the weather had become more severe. The wind was about 20 mph, the swells had increased to about 8 ft (with a shorter period) and whitecaps were prevalent. It was decided that a clamp should be attached to SEMS, and a marker buoy left at the SEMS location. The sub brought down a 3.5 in. hook with a safety latch. This hook was specially constructed by UG. The intent was to attach the hook onto the SEMS frame. Unfortunately, the safety latch proved to be too stiff for the sub to attach. Furthermore, a marker buoy line became entangled on the hook causing the need to abort the operation. A marker buoy was left near the SEMS unit, and the boat returned to shore at about 5:15 p.m.

On 12/9/87, The Mother Goose left port at about 5:30 am and arrived at the SEMS site at about 6:45. The sea conditions were significantly better than the previous day. There were negligible winds, and small long ocean swells. At about 7:15, the sub dove near where the marker buoy was left and easily found the SEMS unit. Between 7:30 and 8:30, attempts were made to remove the probe. Rather than sucking sediment with a pump, air (from the sub's ballast system) was injected into the hole through a tube. The tube was forced under the sediments by the sub and the air release resulted in loosening the more consolidated sediments. The sub grabbed hold of the cable with the manipulator and the sub maneuvered in circular patterns to further loosen the soil. The sub then pulled on the cable by releasing ballast. This three step operation (air injection, cable pivoting, and pulling) was performed several times, and by 8:30, the probe had been pulled up by about 12 in.

The sub then returned to the surface to get new air and to bring the 3.5 inch hook (with a new, less stiff safety latch) down to the SEMS unit. By 9:30, the hook was successfully attached to the SEMS frame, and buoys were tied off at the surface to retain a reasonable slack on the line and to mark the SEMS location.

Between 9:30 and 11:40, the sub attempted to remove the probe using the 3-step procedure described above. During this time, about 30 minutes were spent correcting a potentially dangerous problem. The submarine manipulator had become stuck on the probe cable and needed to be worked free. After this mishap, the probe excavation operations continued, and at about 11:40 am, the probe was successfully removed.

At about 12:00, the Vicki Anne hoisted the SEMS unit off the seafloor. The hoisting began on a down-swell to avoid dropping the SEMS back down to the seafloor. The SEMS was hoisted to a water depth of about 25 ft. UG then deployed a diver who attached a safety line to the SEMS unit, placed the probe into the plastic storage tube on the SEMS frame, and connected a sling through the frame for hoisting SEMS on-board. By about 1:00 p.m., SEMS was on board the Vicki ANNE and headed for port. The SEMS unit was delivered to the Coast Guard Support Center on Terminal Island at about 2:30 p.m. A photograph of the recovered SEMS unit is shown in Figure 1.

LABORATORY WORK: POST-RECOVERY TESTING

After recovery of the Beta field SEMS unit, various preliminary tests were performed on the operational SEMS unit. These tests were performed at the U.S. Coast Guard Support Center on Terminal Island (San Pedro CA.). The objective of these tests was to observe the operation of SEMS under battery powered conditions. This would enable a comparison to be made between battery operation and a.c. operation and to eliminate the possibility that the batteries are adversely affecting the SEMS operation.

Since SEMS was left in a data gathering mode during the recovery operations, the contents of the post-recovery SEMS memory was investigated. An investigation of the contents of SEMS memory indicated that all 56 bubble memory registers had been written to during the recovery operations on December 9, 1987. Some of the events were quite large (more than 1 g of acceleration). These large events occurred between 11:30 a.m. and 12:30 p.m., which was when the probe was released from the soil and SEMS was hoisted on board. Several events were recorded after the SEMS was brought ashore. Some of the on-shore events were characteristic of the noise events recorded while on the seabed, further verifying the electronic nature of the noise.

Various probe vibration tests were performed and indicated that the probe was healthy. Observations of the SEMS trigger mechanism were made and system voltages and currents were measured. The magnetometers were tested by taking readings as the probe was rotated through increments of 90 degrees. The magnetometer readings were in agreement with the probe rotation. The release mechanism was tested by disconnecting the explosive bolt and placing a voltmeter at the bolt connectors. The command was issued to fire the bolt, and 15 volts appeared at the terminals. It appears that the bolt itself must have failed. When the system is operated under a.c. power, a comparison will be made with these post-recovery measurements.

During the afternoon of 12/10 and the morning of 12/11, the battery pressure vessels were opened. The battery arrays were disassembled and the batteries were placed in D.O.T. approved containers for safe transportation.

ANALYTICAL WORK

During this quarter, various techniques were considered for predicting the response of saturated sediments to earthquake-induced seismic activity. Through extensive literature searches and discussions with experts in the field, several modelling techniques for predicting seafloor ground motions have been identified. The modelling methods can be summarized as follows:

1. Analytical Approach. With this method, ground motions are computed by using analytical models. The models involved would generally include; source mechanism modelling, wave propagation modelling, and soil response modelling.

2. Empirical Approach. With this method, seismic predictions are made based on previous observations of recorded ground motion. The empirical approach is usually based on a regression analysis which can include parameters for source mechanism and soil types.

3. Combined Analytical and Empirical Approach. With this method, the best aspects of the analytical and empirical approaches are combined.

Considering that Sandia's funds for this project are primarily committed to developing and deploying SEMS units, it is inconceivable that Sandia can properly pursue seabed motion modelling using all three approaches. As an alternative, Sandia will use the following methodology for seafloor response modelling: develop a regression analysis (empirical approach) which will compare SEMS data records with both land-based records and an historical database; develop soil response models which incorporate saturated sediments and varying-depth water columns; compare predictions for land measurements and sea measurements, using the empirical approach, and apply corrections found from the analytical approach. Due to time/budget constraints, the empirical modelling will be postponed until FY 1989. The analytical modelling, however, will be started in first quarter of CY 1988. The analytical modelling is being performed in cooperation with the Scripps Institute of Oceanography. The principal investigator at Scripps is T. Nogami, who is well known for his expertise in the areas of seismic modelling and soil/pile interaction.

An additional activity during this quarter involved the transfer of Shell platform earthquake records to Sandia. Shell has provided mud-line accelerometer records for the July 1986 earthquakes (which were simultaneously recorded by SEMS) and the October 1987 Whittier Earthquake. Sandia intends to compare these platform records with SEMS records. A comparison may yield some insight into SEMS' failure to record the Whittier Earthquake.

NEXT QUARTER ACTIVITIES

Proposed activities for next quarter include:

1. Extensive testing of recovered SEMS unit.
2. Duplication of recovered SEMS unit for aiding in the redesign effort.
3. Continue evaluation of new probe emplacement procedures.
4. Complete enhancements and debugging of SEMS data reduction software.
5. Re-program and debug SEMS microprocessor.
6. Begin new SEMS design upgrades.
7. Begin development and implementation of advanced SEMS trigger algorithm.

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Figure 1. Recovered Beta Field SEMS unit as it is hoisted from the ocean.

